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PRELIMINARY MEASUREMENTS OF THE NOISE CHARACTERISTICS OF SOME JET-AUGMENTED-FLAP CONFIGURATIONS

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON
January 1959

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SUMMARY

Experimental noise studies were conducted on model configurations of some proposed jet-augmented flaps to determine their far-field noise characteristics. The tests were conducted using cold-air jets of circular and rectangular exits having equal areas, at pressure ratios corresponding to exit velocities slightly below choking. Results indicated that the addition of a flap to a nozzle may change both its noise radiation pattern and frequency spectrum. Large reductions in the noise radiated in the downward direction are realized when the flow from a long narrow rectangular nozzle is permitted to attach to and flow along a large flap surface. Deflecting or turning the jet flow by means of impingement on the under surfaces increases the noise radiated in all directions and especially in the downward direction for the jet-flap configurations tested. Turning of the flow from nozzles by means of a flap turns the noise pattern approximately an equal amount. The principle of using a jet-flap shield with flow attachment may have some application as a noise suppressor.

INTRODUCTION

Recent research work on powered lift devices has indicated that they may be very useful for shortening the landing and take-off runs for aircraft. (See refs. 1, 2, and 3.) These devices generally make use of the power available in the propulsion system to increase greatly the lift from the wing at low forward speeds of the airplane. In the case of the jet airplane, this is done by turning the exhaust stream of the jet engine so that it attaches to the upper surface of the trailing-edge flap in such a manner as to increase substantially the circulation on the wing. Performance studies thus far have been directed toward two general schemes of engine-wing configurations for this purpose. One of these is the external-flow jet-augmented flap, wherein the jet exhaust exits from a pod-mounted engine through a conventional nozzle and is then directed upward by a small deflector through the slot and over the flap which then turns the jet downward in the form of a flattened sheet. Another is the internal-flow jet-augmented flap, wherein the jet exhaust exits from an engine through a long narrow slot-type nozzle near the wing trailing edge ahead of the flap.

It is apparent that these powered lift devices could alter the noise radiation patterns of the airplane. Since these devices will be used in landing and take-off at low altitudes over communities near airports, the noise may become an important consideration. Very little, if any, information on the noise pattern is available, and studies were made to examine the noise characteristics of some of these proposed devices, particularly in the downward direction which is of significance to the person on the ground.

The present paper contains the results of some far-field noise studies of several internal- and external-flow jet-augmented flaps. Measured radiation patterns and frequency spectra are presented for each configuration and are compared with those for the basic nozzles without flaps.

SYMBOLS

D	diameter of circular-nozzle exit, in.
h	minimum height of rectangular-nozzle exit, in.
l	length along flap upper surface, in.
r	distance of microphone from nozzle exit, in.
w	width of rectangular-nozzle exit, in.
γ	microphone location with respect to jet-axis center line, measured from nozzle exit, deg
θ	deflection of flap from zero position, measured from trailing edge, deg

APPARATUS AND METHODS

Descriptions are given of the basic nozzles to which flaps were attached and the various internal- and external-flow jet-flap configurations tested. The techniques for obtaining the data and the instrumentation used are also described.

Nozzle Configurations

The basic-nozzle exit configurations, shown in figure 1, included a circular nozzle of 1-inch diameter and three rectangular nozzles with w/h equal to 10, 50, and 200. Each of the rectangular nozzles had approximately the same exit area as the 1-inch-diameter circular jet nozzle and was constructed of 3/16-inch steel, strengthened along the upper and lower surface of the exit by steel reinforcing plates to prevent changes in the nozzle exit area under test conditions. No attempt was made to design the nozzles with the proper area ratio for optimum design flow conditions. These basic nozzles were then tested in conjunction with the internal-flow configurations of figure 2 and the external-flow configurations of figure 3.

Flap Configurations

The internal-flow configuration of figure 2(a) consisted of wooden flaps attached to the exit of the rectangular nozzle having $w/h = 200$. The length l of these flaps varied from $1\frac{1}{2}$ inches to 12 inches and the flap deflections δ were 0°, 30°, and 60°. The rectangular nozzle ($w/h = 50$) was also tested with the largest flap having a deflection of 30°. The configuration of figure 2(a) was used for most of the testing, wherein the jet flow clung to the flap surface and was turned as it emitted over the flap surface. A few additional tests were conducted wherein turning was obtained by forcing the flow against the lower surface of the flap, as in figure 2(b). In these tests, the shortest and longest flaps with deflections of 30° were attached to the rectangular nozzle ($w/h = 200$).

The two external-flow jet-flap configurations shown in figure 3 incorporated a wing-flap combination which had relative dimensions of wing chord and flap length consistent with some proposed transport-aircraft designs. These wing-flap combinations were used in conjunction with the 1-inch-diameter circular nozzle as indicated in figure 3(a) and the rectangular nozzle ($w/h = 200$) shown in figure 3(b). Deflection of the jet upward was accomplished by means of deflector plates set at such an angle as to direct the main part of the flow through the flap slot.

Instrumentation

The instruments used consisted of a commercially available condenser-type microphone system having a frequency response that is flat within 3 decibels from 20 to 12,000 cps. The microphone signal was fed to a sound-level meter in which the frequency response of the amplifier was flat to 20,000 cps. Frequency analyses of the noise were obtained with a one-third-octave-band analyzer. For a few tests of the configuration of figure 1(d), a sound-measuring system which has a flat response within 2 decibels from about 20 to 30,000 cps was used to measure the spectra at the higher frequencies.

Test Arrangement

Each of the configurations was tested for conditions corresponding to zero forward velocity. The configurations were fitted to the end of a settling chamber in combination with a muffling section for the purpose of minimizing extraneous noise generated inside the chamber and at the control valve. The apparatus was directed outdoors so that the nozzle being tested would extend 9 feet away from the building and about 20 feet above the ground. This procedure minimized reflections. The background noise level during the tests was from 64 to 72 decibels.

All tests were conducted at a nozzle pressure ratio of 1.82, so that comparable mass-flow conditions would exist for each configuration. Far-field noise surveys were made on each configuration at a microphone distance r of 108 inches (108 circular-jet diameters), and the overall noise level and frequency spectra were obtained. The microphone was suspended in the noise field of the jet from a 20-foot survey boom located outside the building and by this means could be moved to any desired location with respect to the jet. Since most of the configurations tested did not have radially symmetrical noise patterns, the survey scheme of figure 4 was used. Measurements were made at a constant distance r from the nozzle exit which was located at the origin of the figure, the locus of measurements being on the surface of a sphere. Data were obtained in the XZ-plane, the YZ-plane ($\gamma = 90^{\circ}$), and in one plane parallel to the YZ-plane as defined by the microphone location γ. Sufficient data points were obtained in each survey plane to define the noise contours.

RESULTS AND DISCUSSION

The results are presented in the form of polar plots of the overall noise levels in several survey planes, along with the frequency spectra of the noise radiated in the downward direction. These results are presented for the basic nozzles in figures 5 and 6, for the internal-flow jet flaps in figures 7 to 9, and for the external-flow jet flaps in figures 10 to 12.

Basic Nozzles

Noise radiation patterns.- The effect on the radiation pattern of changing the nozzle exit from a circular to a rectangular shape is illustrated in figure 5. Overall noise levels in decibels are plotted as a function of azimuth angle for each of the basic-nozzle configurations in the XZ-plane and in two parallel planes which are each perpendicular to the XZ-plane. (See fig. 4.) In figure 5(a), the nozzle exit is located at the origin and the flow is from left to right and along the X-axis. These noise radiation patterns are, as would be expected, symmetrical about the jet axis. The pattern for the circular nozzle has its maximum noise radiation at about 40° from the jet axis rearward of the nozzle. As the nozzle geometry is changed from the circular to the rectangular configurations for the tests, the maximum noise radiation occurs at angles slightly greater than this, namely between 50° and 60°. Although there is very little change in the noise level along the maximum radiation line, there does appear to be a slight reduction in the noise radiated in the plane of the nozzle exit and ahead of the nozzle exit as w/h is increased. It can be noted in figure 5(a) that the curves are not continuous to the jet axis. Although noise-level readings were not obtained in this region of the jet exhaust because of the wind-blast effects on the microphone, it is believed that a minimum noise level occurs on the jet axis. The noise radiation patterns shown in figure 5(b) indicate further significant differences between the basic-nozzle configurations. In changing from a circular to a rectangular nozzle, the noise radiation patterns are skewed from a radially symmetrical or circular shape to an oval shape with increasing w/h.

Some exploratory velocity profiles were measured in the mixing region of the rectangular nozzle for comparison with those of the circular jet, and it was found that there is a tendency for the rectangular jet to spread more rapidly in the plane of the small dimension than the circular jet. Although this effect is not fully understood, it appears that the skewing of the noise patterns is associated with the jet spreading.

Frequency spectrum.- An analysis of the frequency content of the noise emitted from each of the basic-nozzle configurations in the downward direction was made, and the results for the circular and rectangular nozzle ($w/h = 200$) are shown in figure 6. In this figure the noise level is given in decibels per unit band width. Although the spectra for the intermediate rectangular nozzles are not shown, the shapes of the spectra indicated a systematic variation. Inspection of figure 6 indicates that for the radical change in nozzle configuration, from a circular nozzle to a rectangular nozzle ($w/h = 200$), there is a tendency for the acoustic energy to shift to the higher frequencies with the result that there are sizable reductions in the lower end of the spectrum at the expense of increases in noise levels at the higher frequencies. This is in general agreement with results obtained in references 4 and 5 and is beneficial because of the large atmospheric losses at the higher frequencies. Determination of the frequency at which the curve for the rectangular nozzle ($w/h = 200$) began a downward trend was obtained with the high-frequency sound-measuring system. The data indicated that the maximum noise level occurred at a peak frequency of about 20,000 cps. In summation of figures 5 and 6, it appears that a very large change in w/h must be made before any significant noise benefits can be realized.

Internal-Flow Jet Flaps

Noise radiation patterns.- Figure 7 presents the noise radiation patterns of a survey in the XZ-plane for a rectangular nozzle ($w/h = 200$) with δ equal to 0°, 30°, and 60°. Data are presented for flap-length—nozzle-height ratios l/h of 20 and 190 and for the no-flap condition taken from figure 5. In comparing the results of the tests for the short straight flap ($\delta = 0^\circ$) with those for the no-flap case, it can be seen that only minor changes occur to the radiation patterns. In particular, the noise radiated in or near the plane of the nozzle exit is generally increased. As the flap deflection angle is increased it can be seen that the noise patterns become more unsymmetrical in the XZ-plane. In fact, the whole noise pattern is seen to undergo an angular displacement about the origin, of approximately the same amount the jet exhaust is turned. Attachment of the flow to the flap surface for a given flap deflection is dependent upon the pressure ratio, minimum slot dimension, and flap radius. (See ref. 1.) For the conditions of the present tests, these requirements were met and, in addition, shadowgraph pictures indicated that the flow was attached in all cases.

If the flap is lengthened considerably, the results are somewhat different as illustrated in figure 7(b). In this case, the length of the flap is noted to be significant as well as the deflection angle. The large flap surface reduces the noise levels somewhat in the upward direction and apparently acts as an acoustic shield in the downward direction. This results in large noise reductions below the flap in all cases. However, in the case of the 60° flap deflection, the noise pattern is turned to such an extent that the angle of maximum radiation formerly occurring on the top is now directed downward. This result suggests that the flap length may become less significant as the deflection of the flap is increased to large values.

These results are further illustrated by the data of figure 8, which apply to survey planes perpendicular to the XZ-plane. It can be noted that none of the radiation patterns are radially symmetrical and that they are influenced by both the flap length and deflection.

The $w/h = 50$ rectangular nozzle was tested with the largest flap of 30° deflection for comparison with the $w/h = 200$ rectangular nozzle incorporating the same flap. The results indicated that the radiation patterns are of about the same shape but the noise levels for the

$w/h = 50$ rectangular nozzle and the largest flap are somewhat greater in all directions, mainly in the downward direction. No information is available on the effects of flap width (spanwise direction) on the noise generated for a given rectangular nozzle.

The results of tests wherein the flow was turned by forcing it against the flap surface (see fig. 2(b)) indicated that, in general, the noise radiated in the downward direction was increased over that obtained with the configuration of figure 2(a). Shielding benefits associated with the larger flaps occurred for the configuration of figure 2(b) above the flap or in the upward direction.

Frequency spectrum.- Figure 9 presents the frequency spectrum of the noise radiated downward at microphone locations γ of 52° and 90° from the rectangular ($w/h = 200$) nozzle with turning flaps of various lengths attached. Data were obtained also for flap deflections δ of 0° and 60° and the results were noted to be consistent with those shown in figure 9 for $\delta = 30^{\circ}$. Also included for comparison are spectra for the nozzle without flaps from figure 6. It can be seen that each of the spectra has a broad peak as is characteristic of mixing noise from jets. It can also be seen that this peak in the spectrum occurs at lower frequencies as the flap length increases. This result apparently arises in part from a decrease in the levels at the high end of the spectrum as a result of the shielding action of the flap surface. There is an accompanying increase in levels at the low end of the spectrum as the flap length is increased. This latter phenomenon is not well understood but is thought to be associated with the flow conditions on the flap surface rather than with the dynamic characteristics of the flap itself.

Comparison of the spectra for the $w/h = 50$ rectangular nozzle and the $w/h = 200$ rectangular nozzle, each having the same large flap with a deflection of 30°, indicated that the two curves were quite similar in shape but vertically displaced somewhat due to the difference in overall noise level.

The spectra obtained for the configurations of figures 2(a) and 2(b) were markedly different. In general, it can be said that the noise spectrum of the configuration of figure 2(b) in the downward direction closely simulates that of the rectangular nozzle ($w/h = 200$) with no flap. Likewise, the spectrum in the upward direction closely resembles that of the configuration of figure 2(a) in the downward direction. (Also see fig. 9.) The low-frequency phenomenon discussed previously now occurs in the upward direction.

External-Flow Jet Flaps

Noise radiation patterns.- Radiation patterns for two different external-flow configurations are shown in figure 10. Both the circular and the rectangular nozzle ($w/h = 200$) were tested with a wing-flap configuration having a flap deflection δ of 60° as previously described. (See fig. 3.) Also shown for comparison are the radiation patterns for the basic nozzles alone (fig. 5) and for the basic nozzles in proximity to a wing but without turning or impingement of the flow.

In figure 10(a) it can be seen that the presence of the wing as a reflecting surface alters the radiation pattern from the circular nozzle. This results in lower noise levels in the upward direction and higher noise levels in the downward direction. When the flow is deflected upward to impinge on the under surface of the wing and then is directed through the slot and turned over the flap, it can be seen that higher noise levels occur at nearly all azimuth angles. In particular, the noise levels in the downward direction are increased substantially. This increased noise is believed to arise from flow impingement on the nozzle deflector and the wing and flap surfaces.

As a matter of interest, a configuration such as shown in figure 3(b) was tested to determine its noise characteristics. The results obtained from this test are presented in figure 10(b) and indicate that the resulting noise levels are comparable to those for the circular nozzle.

These findings are further illustrated by the data of figure 11 for the same test conditions. These latter data were recorded in planes perpendicular to the XZ-plane and at microphone locations γ of 52° and 90°. Again it may be seen that the higher noise levels occur generally in the downward direction for both external-flow configurations tested.

In summary of figures 10 and 11, it appears that, for the external-flow arrangements tested, the noise levels are greater in all directions for the external-flow jet-flap configurations than they are for the basic-nozzle configurations, the greatest increases being in the downward direction.

Frequency spectrum.- So far only the overall noise levels have been discussed. It is also of interest to examine the frequency content of the noise radiated downward from the two external-flow configurations shown in figures 10 and 11. These data are shown in figure 12 for the two microphone locations of 52° and 90°. It can be seen that the spectra are quite similar for the two different nozzles when the jet flow is deflected as in figures 10 and 11. This is in contrast to the data of figure 6 which show different spectra for these two nozzles. Thus, it follows that the noise from the external-flow configuration is mainly from the impingement of the flow on the under surface of the wing rather than the jet mixing. This would indicate that any benefits which may be realized by incorporating a rectangular nozzle would be nullified if it is used in conjunction with the previously discussed external-flow arrangements.

Some Implications of the Data

The tests described herein have produced results that are significant with respect to the applications of devices for turning the gas flow from a jet. For instance, it has been demonstrated that if the flow is deflected by impingement on surfaces, such as for the configurations of figure 3, the noise is greater than if deflection is accomplished by means of a configuration such as shown in figure 2(a). The arrangement of figure 2(a) may also be used to advantage as an acoustic shield for the purpose of reducing the noise in the downward direction.

Acoustic shielding is illustrated with the aid of figure 13 which presents the results from a noise survey taken in the XZ-plane on both the basic circular jet and a rectangular jet having a flap attached. These noise radiation patterns, which are taken from figures 5 and 7, indicate that the slot-flap arrangement gives noise reductions of about 20 decibels along the line of maximum radiation downward and approximately 10 decibels directly below the flap. This suggests the use of a shielding flap for the suppression of noise in the downward direction during take-off and landing. If the jet-exhaust exit were located above the wing, this shield would serve also as a flap for jet-augmented lift and could be used to turn the flow in such a manner as to minimize the noise.

CONCLUSIONS

Results have been presented from an investigation to determine the far-field noise characteristics of some proposed jet-augmented flap configurations. Tests of several jet-augmented flap arrangements having the same exit area and using cold air at nozzle pressure ratios slightly below choking indicate the following conclusions:

1. For the basic nozzles without flaps:

(a) The overall-noise radiation patterns are not radially symmetrical for a rectangular jet having large width-height ratio.

(b) As the width-height ratio increases, the peak of the noise spectrum moves to higher frequencies.

2. For the basic nozzles with flaps:

(a) The addition of a flap to a nozzle may change both its radiation pattern and frequency spectrum.

(b) Turning of the jet exhaust causes the noise pattern to be turned an equal amount.

(c) Large reductions in the noise radiated in the downward direction are realized when the flow from a rectangular nozzle with a large width-height ratio is permitted to attach and flow along a large flap surface.

(d) Deflecting or turning the jet flow by means of impingement on the under surfaces increases the noise radiated in all directions and especially in the downward direction.

(e) The principle of using a jet-flap shield with flow attachment may have some application as a noise suppressor.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., September 16, 1958.

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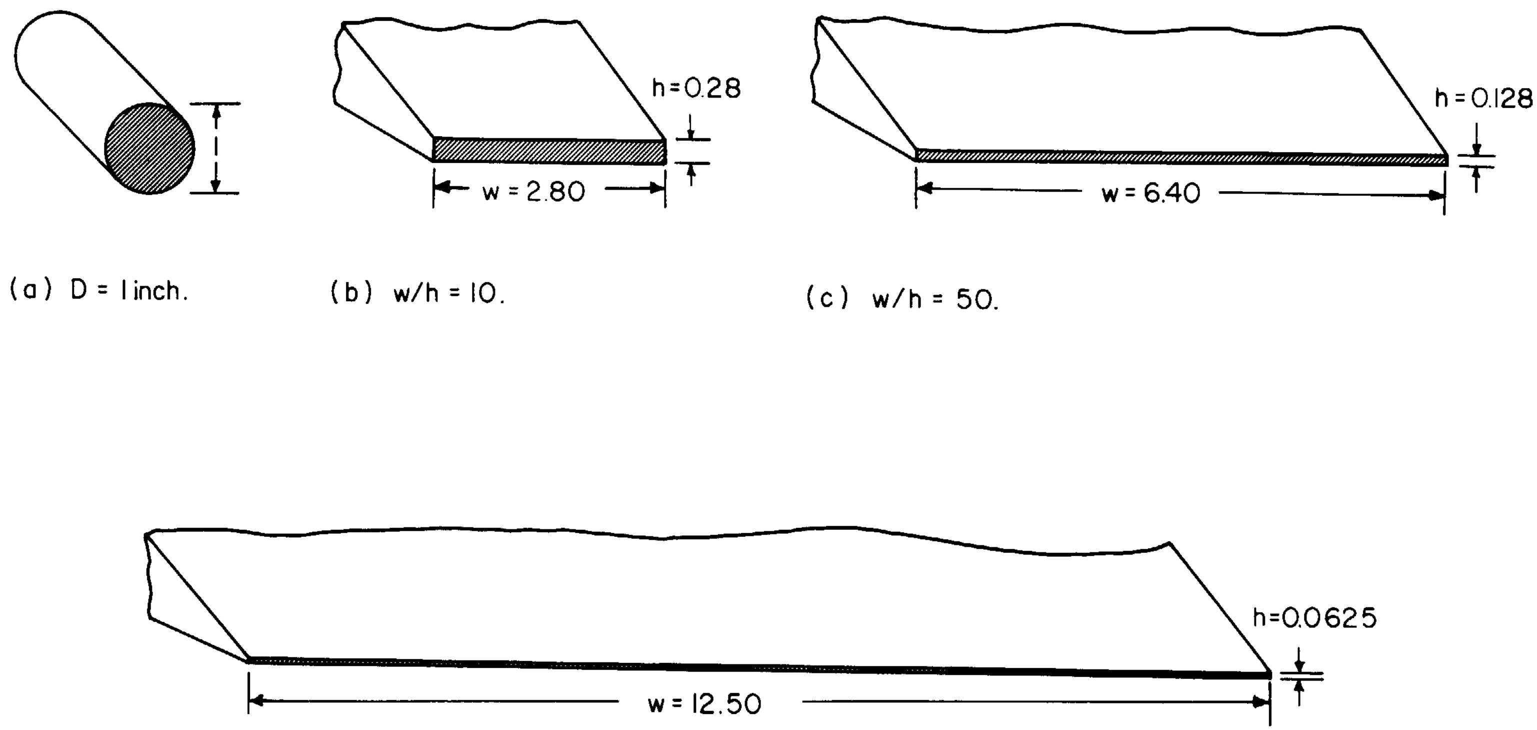


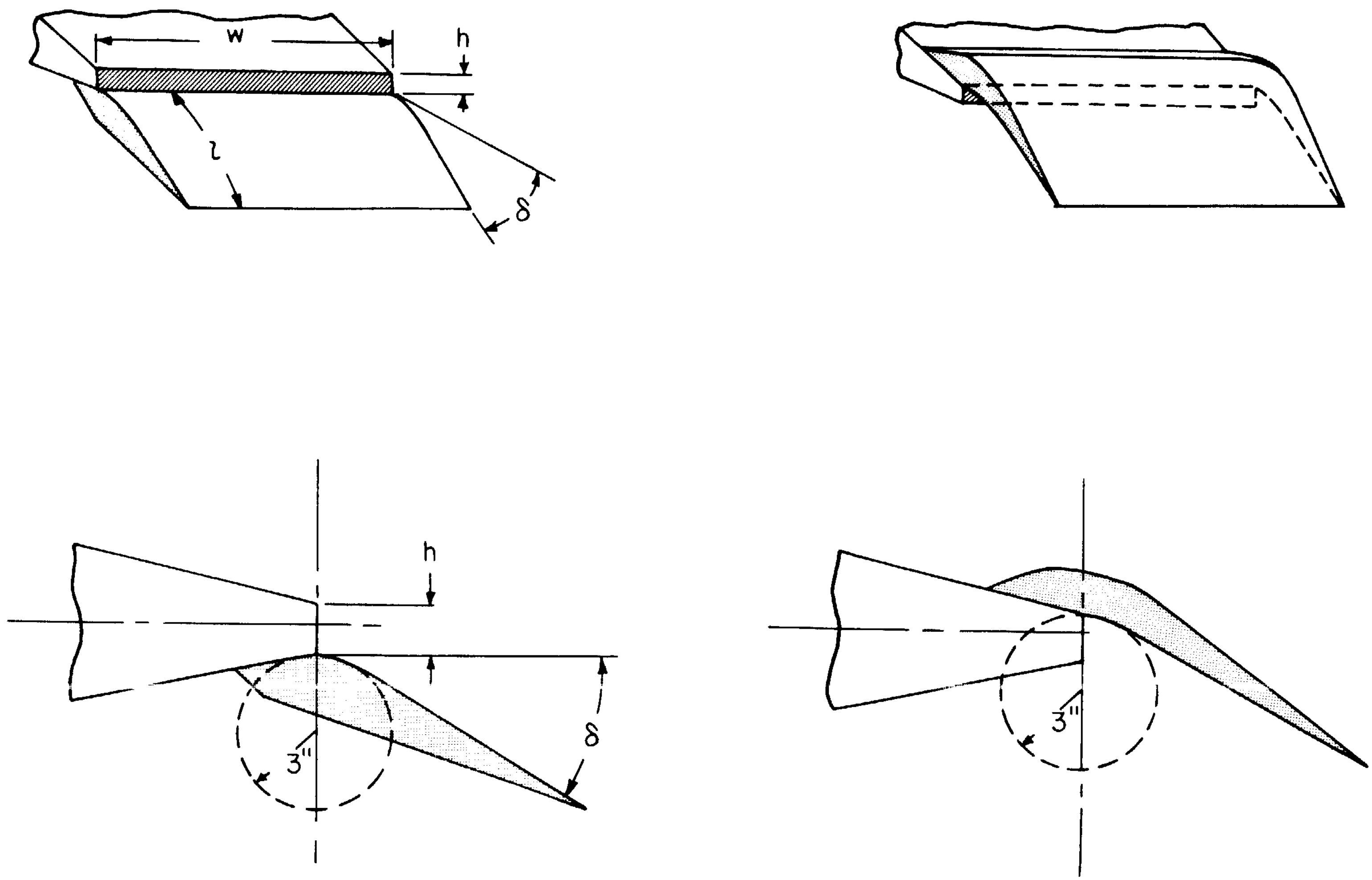
(a) D = 1 inch.

(b) w/h = 10.

(c) w/h = 50.

(d) w/h = 200.

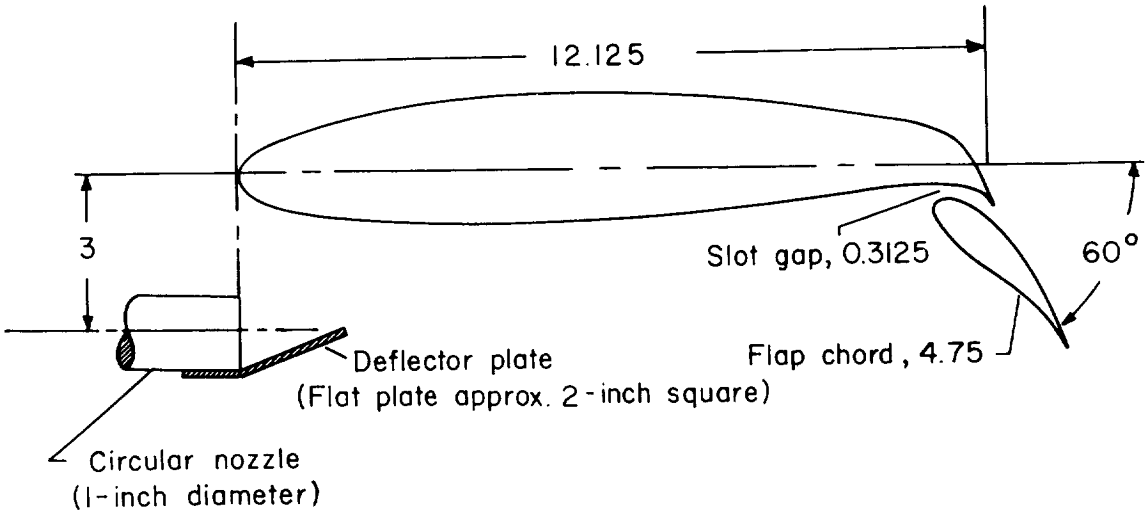
Figure 1.- Basic-nozzle exit configurations. (All dimensions are given in inches.)



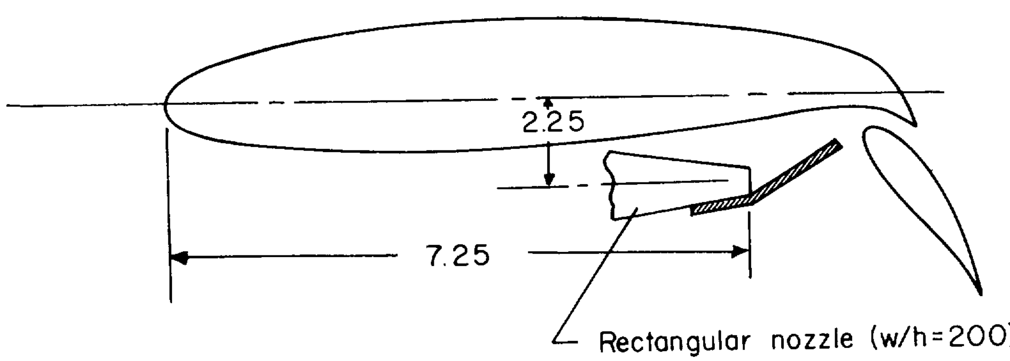
(a) Flap below exit.

(b) Flap above exit.

Figure 2.- Internal-flow jet-augmented flap configurations.



(a) Configuration with circular nozzle.



(b) Configuration with rectangular nozzle.

Figure 3.- External-flow jet-augmented flap configurations. (All linear dimensions are given in inches; wing span is $16\frac{1}{2}$ inches.)

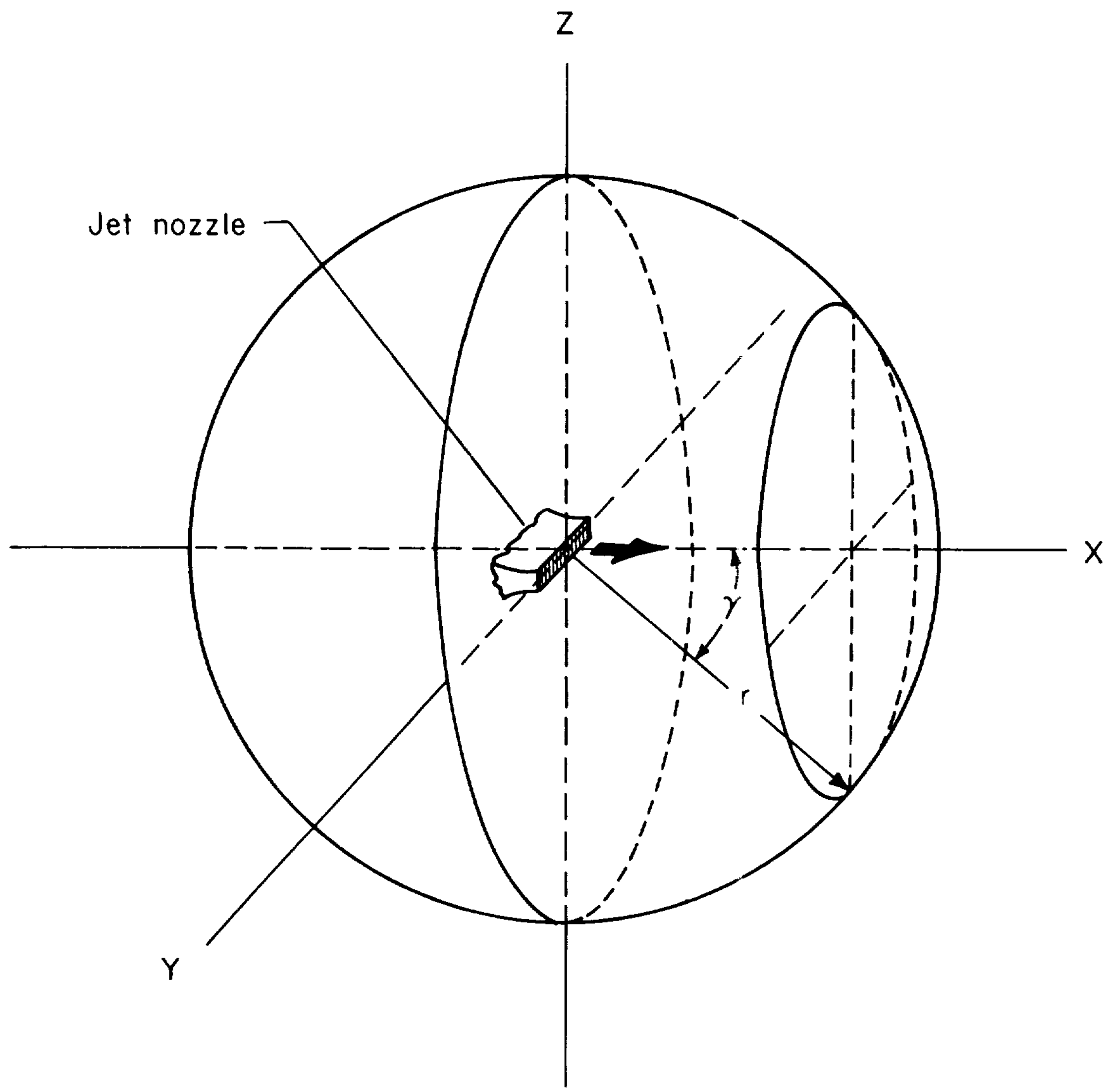
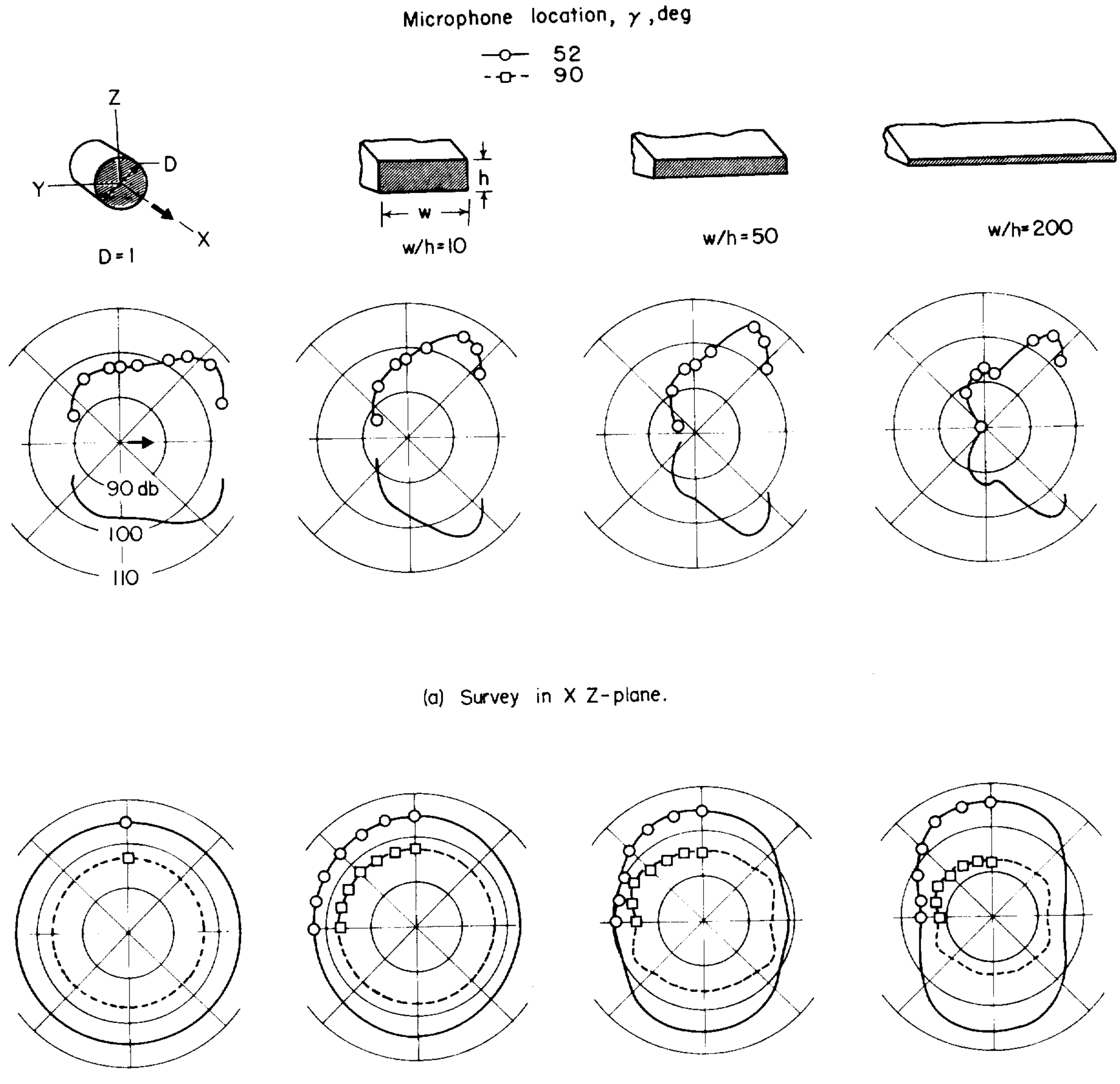


Figure 4.- Coordinate system used for noise surveys.



(a) Survey in X Z-plane.

(b) Survey in planes perpendicular to the X Z-plane.

Figure 5.- Overall-noise radiation patterns of the basic-nozzle configurations. r = 108 inches.

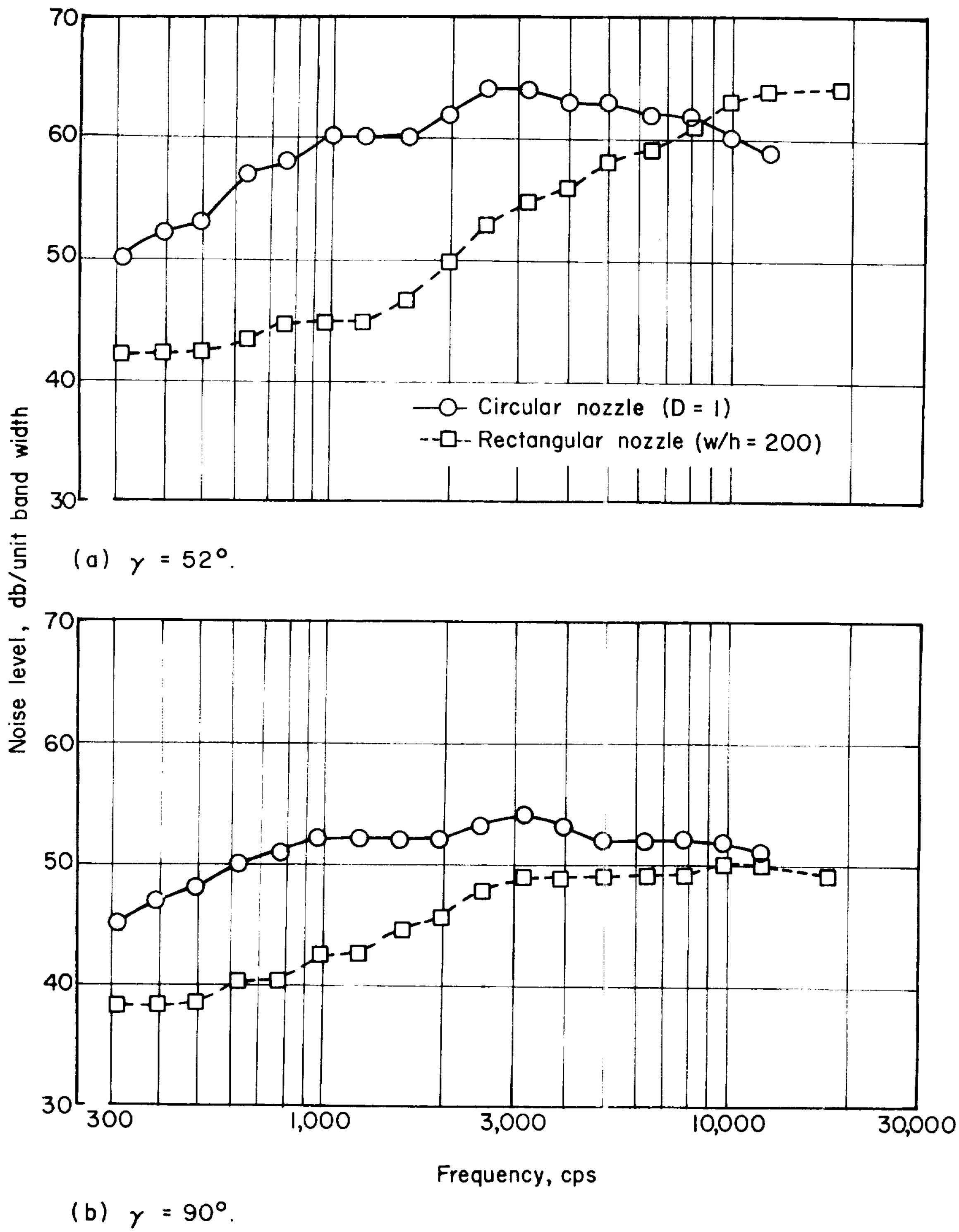


Figure 6.- Effect of basic-nozzle exit geometry on the noise spectrum.

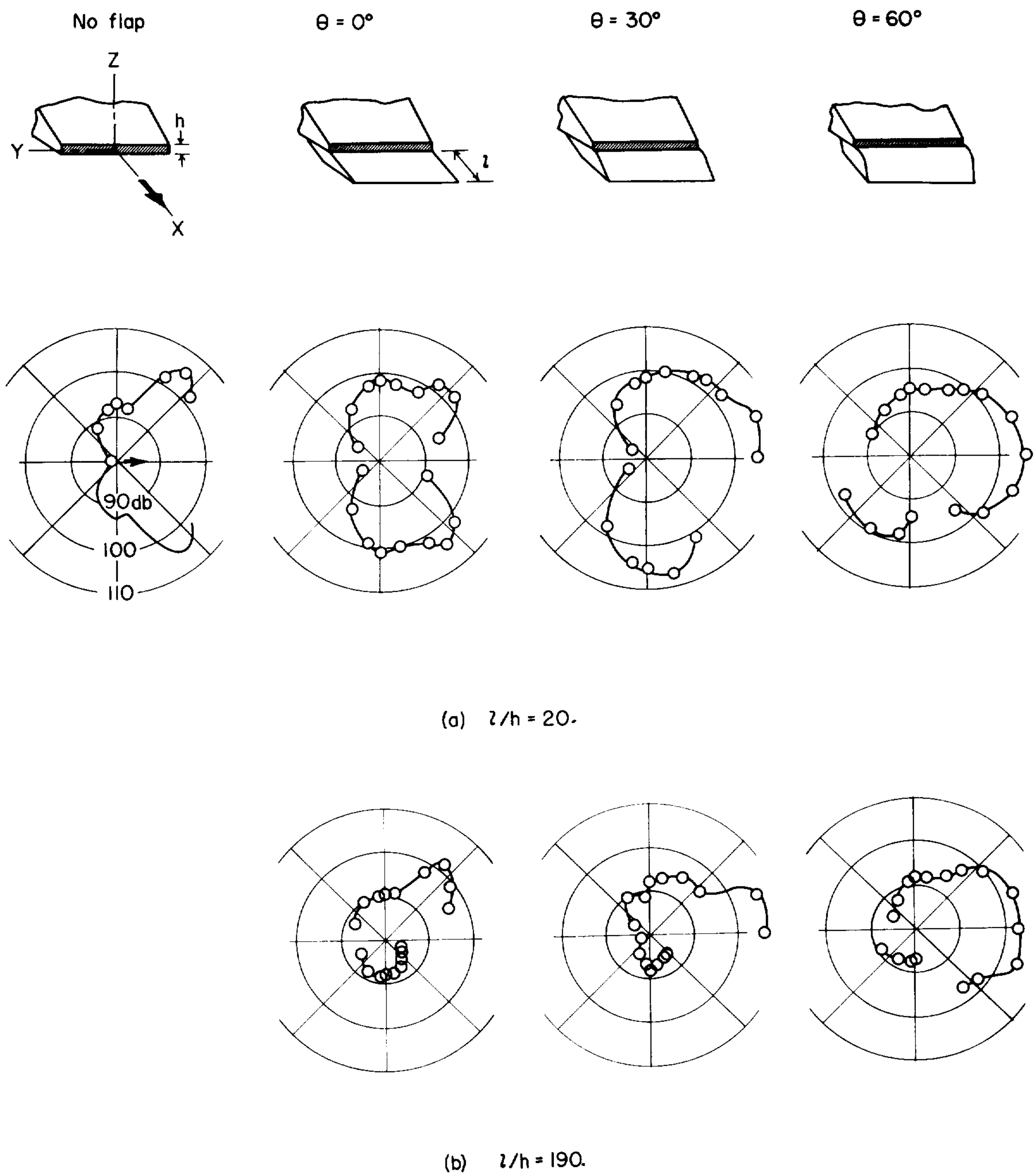


Figure 7.- Overall-noise radiation patterns of a survey in the XZ-plane of the internal-flow configurations using the rectangular nozzle of w/h = 200. r = 108 inches.

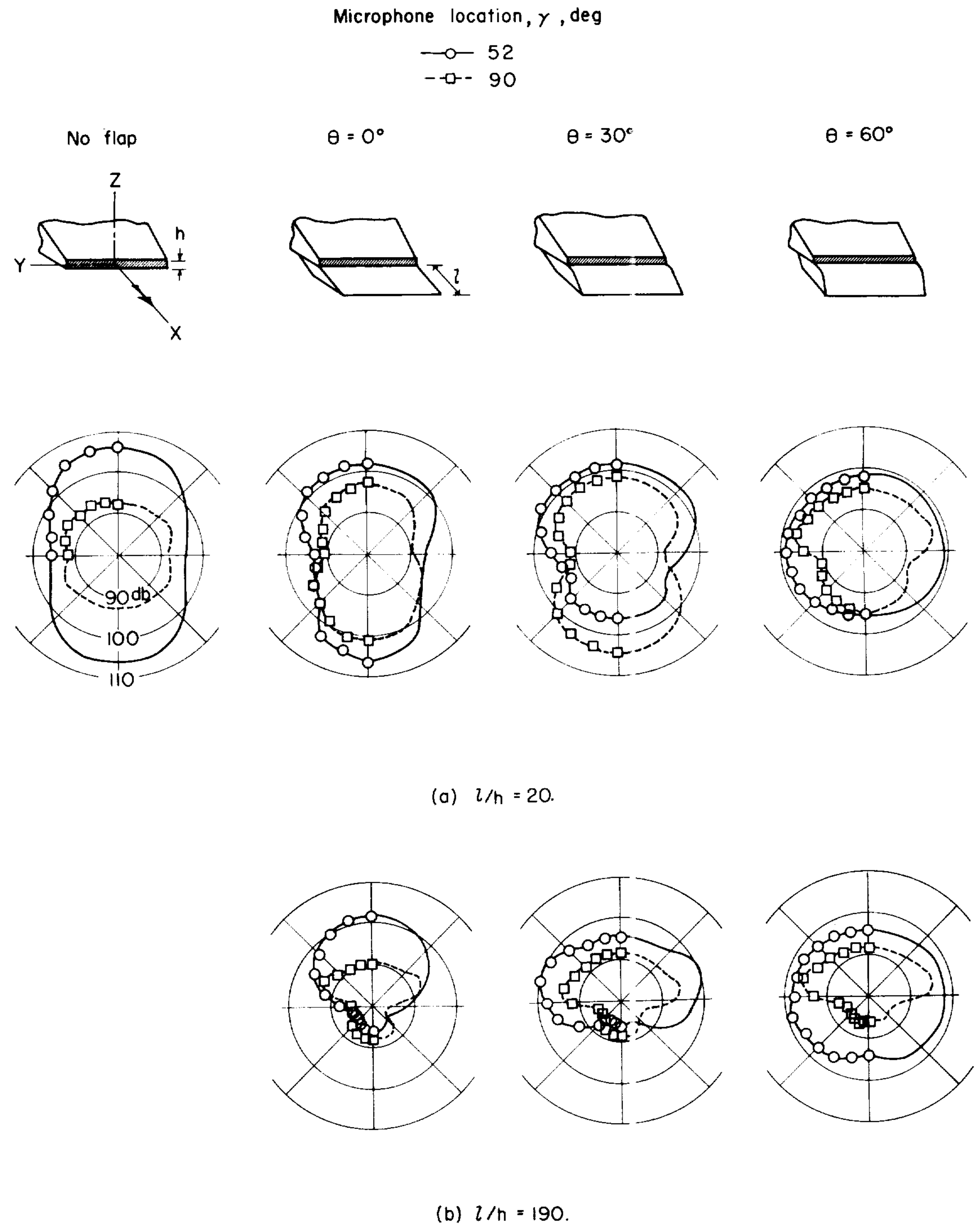


Figure 8.- Overall-noise radiation patterns of surveys taken in two planes perpendicular to the XZ-plane of the internal-flow configurations using the rectangular nozzle of $w/h = 200$. $r = 108$ inches.

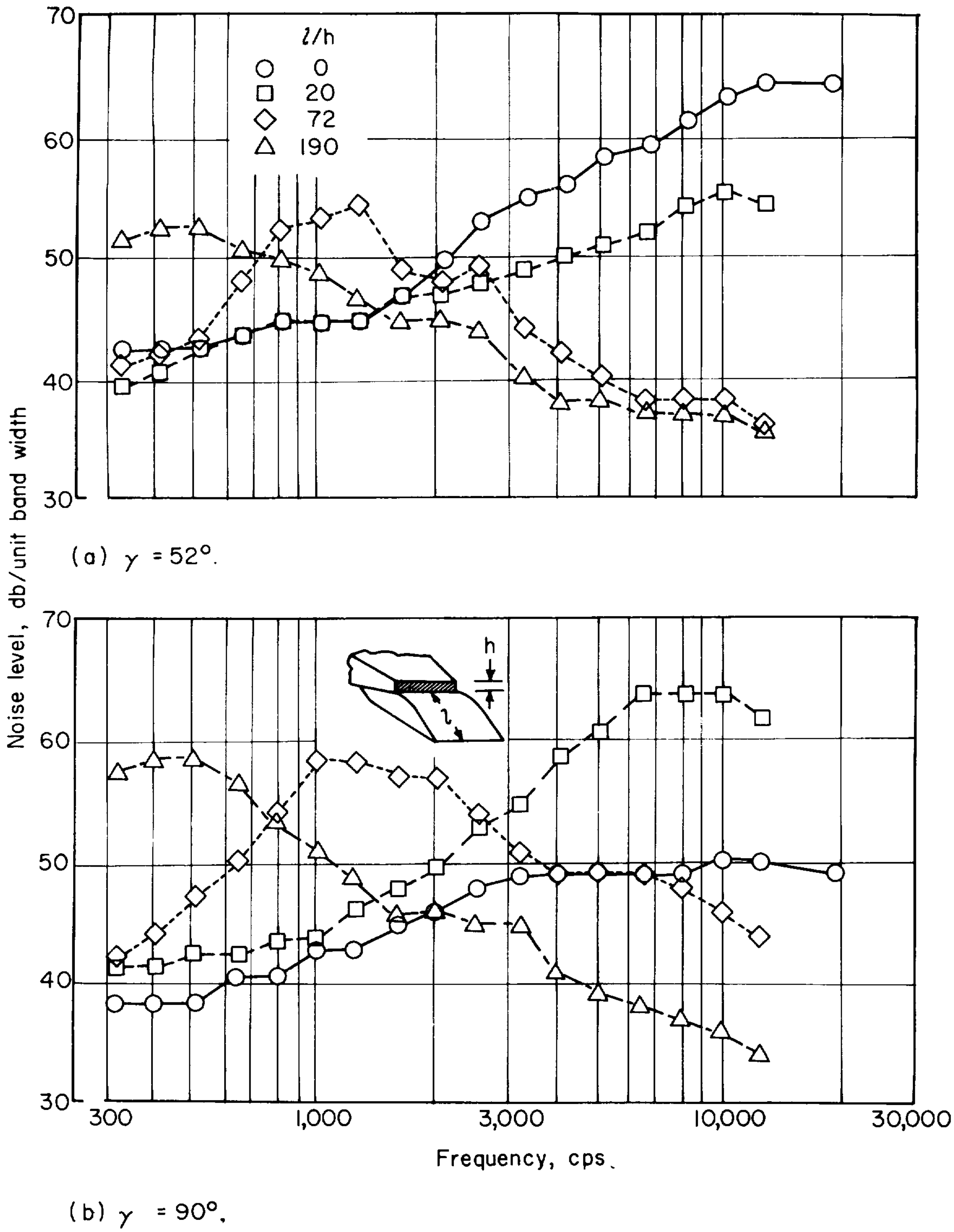
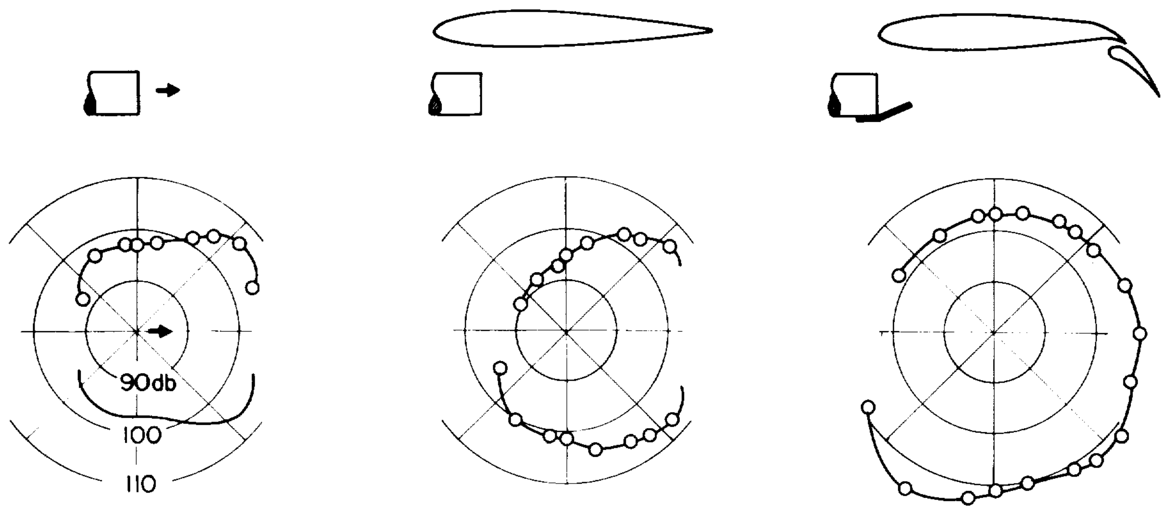
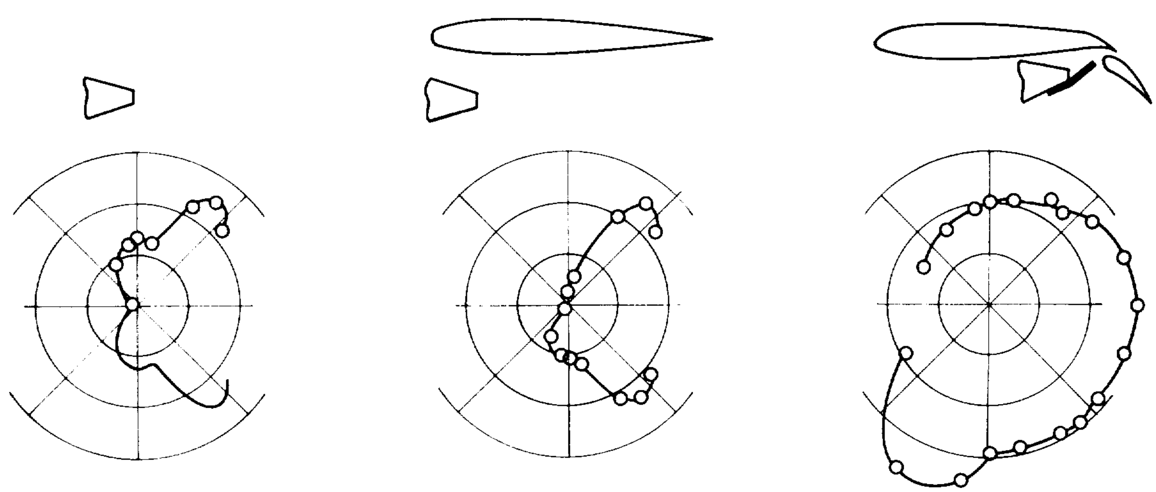


Figure 9.- Effect of flap length on the noise spectrum. Rectangular nozzle of $w/h = 200$ and flap deflection of 30°.



(a) Configuration with circular nozzle (D = 1).



(b) Configuration with rectangular nozzle (w/h = 200).

Figure 10.- Overall-noise radiation patterns in the XZ-plane of the external-flow configurations. Flap deflection, 60°; r = 108 inches.

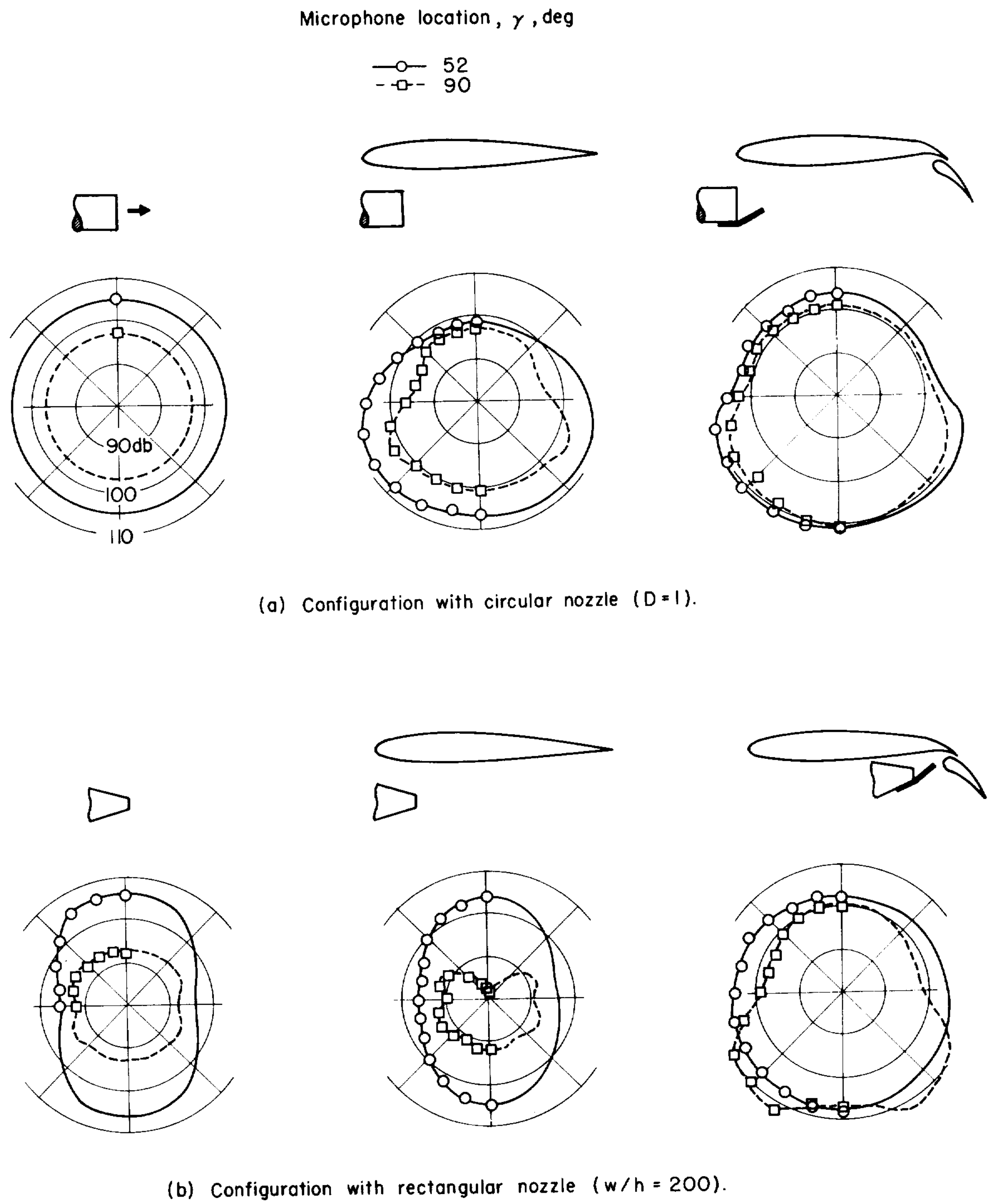
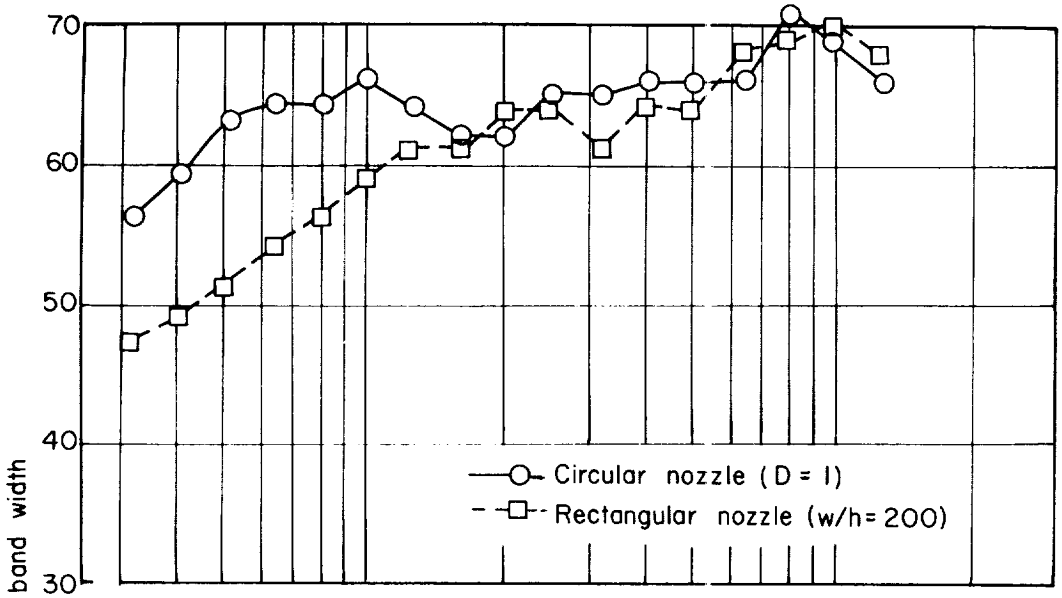
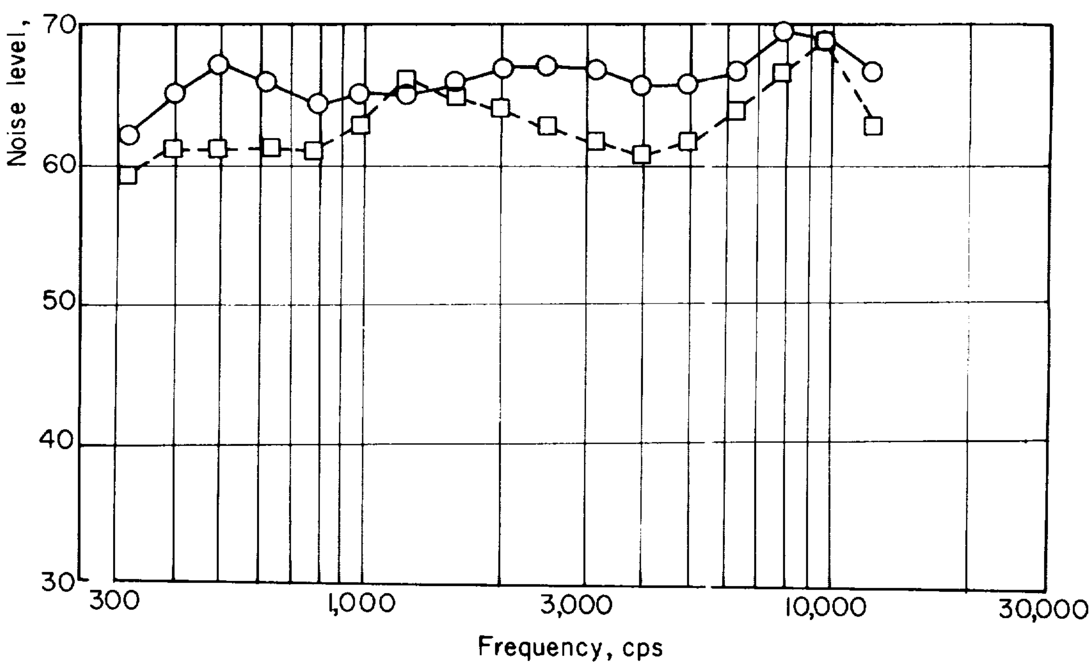


Figure 11.- Overall-noise radiation patterns of a survey in two planes perpendicular to the XZ-plane of the external-flow configurations. Flap deflection, 60°; r = 108 inches.



(a) $\gamma = 52^{\circ}$.



(b) $\gamma = 90^{\circ}$.

Figure 12.- Effect of nozzle-exit geometry on the noise spectrum of the external-flow configurations.

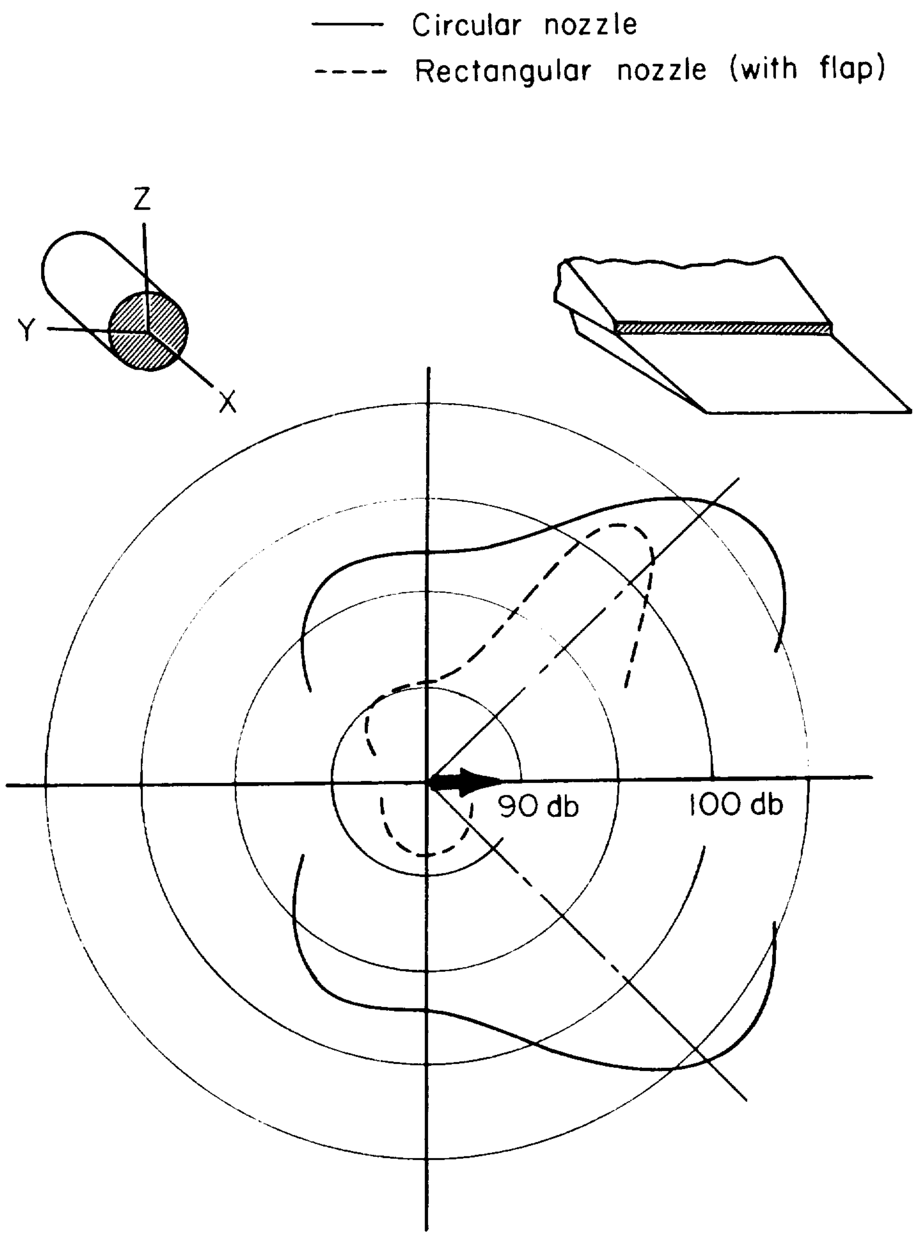


Figure 13.- Overall-noise radiation patterns from a survey taken in the XZ-plane.

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